

Explaining muon magnetic moment and AMS-02 positron excess in a gauged horizontal symmetric model

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Abstract We extended the standard model with a fourth generation of fermions to explain the discrepancy in the muon magnetic moment and to describe the positron excess observed by AMS-02 experiment. We introduce a gauged $SU(2)_{HV}$ horizontal symmetry between the muon and the 4th generation lepton families and identified the 4th generation right-handed neutrino as the dark matter with mass ~ 700 GeV. The dark matter annihilates through $SU(2)_{HV}$ gauge boson into final states $(\mu^+\mu^-)$ and $(\nu_\mu^c \nu_\mu)$. The $SU(2)_{HV}$ gauge boson with mass ~ 1.4 TeV gives the required contribution to the muon $(g-2)$ and satisfy the experimental constraint from BNL measurement.

1 Introduction

The discrepancy between the experimental measurement [1] and the standard model (SM) projection of muon anomalous magnetic moment (in short muon $g-2$) and the excess of positrons observed by AMS-02 [2] are the two interesting signals which may have a common beyond standard model explanation.

In the standard model, the muon anomalous magnetic moment behaves as $a_\mu \propto m_\mu^2/M_{W,Z}^2$ and its contribution is $a_\mu^{\text{SM}} = 19.48 \times 10^{-10}$ [4]. But SM contribution is 3.6σ away from the measured [1] value of muon $g-2$, which states

$$\Delta a_\mu \equiv a_\mu^{\text{Exp}} - a_\mu^{\text{SM}} = (28.7 \pm 8.0) \times 10^{-10}, \quad (1)$$

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where a_μ is the anomalous magnetic moment in the unit of $e/2m_\mu$. The mass suppression in muon $g - 2$ can be evaded by proposing a horizontal symmetry [6, 7].

AMS-02 experiment [2] has observed the excess of positron over cosmic-ray background, which goes upto ~ 500 GeV. The dark matter (DM) annihilation with leptonic final states μ or τ can explain the observed excess very well. The absence of antiproton excess over cosmic-ray background also indicates towards a leptophilic dark matter.

We introduce a 4th generation fermions family and propose a $SU(2)_{HV}$ gauge symmetry between 4th generation leptons and muon families. As an artefact of $SU(2)_{HV}$ gauge symmetry, we have new contributions to muon $g - 2$ from $SU(2)_{HV}$ gauge boson θ^+ and different scalars. In this model, we identified the 4th generation right-handed neutrino $\nu_{\mu'R}$ as dark matter. The annihilation of dark matter takes place through $SU(2)_{HV}$ gauge boson θ_3 with only possible final states $(\mu^+\mu^-)$ and $(\nu_\mu^c \nu_\mu)$. The dark matter stability is insured by taking 4th generation charged lepton heavier than dark matter. The required cross-section to explain AMS-02 positron excess is $\sigma v_{\chi\chi \rightarrow \mu^+\mu^-} = 2.33 \times 10^{-25} \text{cm}^3/\text{sec}$, which is larger than the cross-section $\sigma v_{\chi\chi \rightarrow SM} \sim 3 \times 10^{-26} \text{cm}^3/\text{sec}$ required for getting correct relic density [8].

2 Model

Keeping the exact structure of SM, we add the 4th generation of quarks (c', s') and leptons (ν'_μ, μ') (of both chiralities) into it. In addition we also introduce three-right handed neutrinos and extend the standard model gauge group by proposing a $SU(2)_{HV}$ horizontal symmetry. In this model, we have taken e and τ families as a singlet of $SU(2)_{HV}$ for simplicity and explain muon $g - 2$ and AMS-02 positron excess simultaneously.

The left-handed muon and 4th generation lepton families are denoted by $\Psi_{Li\alpha}$ and their right-handed neutral and charged counterparts are denoted by $N_{R\alpha}$ and $E_{R\alpha}$ respectively. We denote the left-handed electron and tau doublet by ψ_{eLi} and $\psi_{\tau Li}$ and their right-handed equivalent by e_R and τ_R respectively. In this model, the gauge fields correspond to $SU(2)_L \times U(1)_Y \times SU(2)_{HV}$ groups are A_μ^a, B_μ and θ_μ^a ($a = 1, 2, 3$) with gauge couplings g, g' and g_H respectively. The gauge couplings of muon and 4th generation lepton families are given as,

$$\begin{aligned} \mathcal{L}_\psi = & i\bar{\Psi}_{Li\alpha}\gamma^\mu \left(\partial_\mu - \frac{i}{2}g\tau \cdot A_\mu + ig'B_\mu - \frac{i}{2}g_H\tau \cdot \theta_\mu \right)_{ij;\alpha\beta} \Psi_{Lj\beta} \\ & + i\bar{E}_{R\alpha}\gamma^\mu \left(\partial_\mu + i2g'B_\mu - \frac{i}{2}g_H\tau \cdot \theta_\mu \right)_{\alpha\beta} E_{R\beta} + i\bar{N}_{R\alpha}\gamma^\mu \left(\partial_\mu - \frac{i}{2}g_H\tau \cdot \theta_\mu \right)_{\alpha\beta} N_{R\beta} \end{aligned} \quad (2)$$

from eq.2, it is clear that the “neutral current” of $SU(2)_{HV}$ contributes to the annihilation process, $(\nu_{\mu'} \nu_{\mu'}) \rightarrow \theta_3^* \rightarrow (\mu^+ \mu^-), (\nu_\mu^c \nu_\mu)$, which is appropriate for AMS-02 and relic density. The “charged-current” contributes to the muon $g - 2$.

There exist strong bounds on the 4th generation from the higgs production at LHC, so we extend the higgs sector (in addition to ϕ_i) by a scalar $\eta_{i\alpha}^\beta$. As a $SU(2)$ doublet $\eta_{i\alpha}^\beta$ lifts the bounds from higgs overproduction and 125 GeV mass eigenstate is mainly constituted by η . To generate masses for $SU(2)_{HV}$ gauge bosons, we introduce another scalar χ_α , which is a doublet under $SU(2)_{HV}$. The quantum numbers of the scalars and fermions in the model are shown in table.1. After corresponding scalars take their vacuum expectation values (vevs), the masses of the gauge bosons come,

$$M_W^2 = \frac{g^2}{2}(2\langle\eta\rangle^2 + \langle\phi\rangle^2), \quad M_Z^2 = \frac{g^2}{2}\sec^2\theta_W(2\langle\eta\rangle^2 + \langle\phi\rangle^2), \quad M_A^2 = 0, \\ M_{\theta^+}^2 = g_H^2(4\langle\eta\rangle^2 + \frac{1}{2}\langle\chi\rangle^2), \quad M_{\theta_3}^2 = \frac{1}{2}g_H^2\langle\chi\rangle^2 \quad (3)$$

The Yukawa couplings of the leptons are given by,

$$\mathcal{L}_Y = -h_1\bar{\psi}_{eLi}\phi_ie_R - \tilde{h}_1\epsilon_{ij}\bar{\psi}_{eLi}\phi^j\nu_{eR} - h_2\bar{\Psi}_{Li\alpha}\phi_iE_{R\alpha} - \tilde{h}_2\epsilon_{ij}\bar{\Psi}_{Li\alpha}\phi^jN_{R\alpha} \\ - k_2\bar{\Psi}_{Li\alpha}\eta_{i\alpha}^\beta E_{R\beta} - \tilde{k}_2\epsilon_{ij}\bar{\Psi}_{Li\alpha}\eta_{i\alpha}^{j\beta}N_{R\beta} - h_3\bar{\psi}_{\tau Li}\phi_i\tau_R - \tilde{h}_3\epsilon_{ij}\bar{\psi}_{\tau Li}\phi^j\nu_{\tau R} + \text{h.c} \quad (4)$$

which generate the following masses for leptons,

$$m_e = h_1\langle\phi\rangle, \quad m_\tau = h_3\langle\phi\rangle, \quad m_{\nu_e} = \tilde{h}_1\langle\phi\rangle, \quad m_{\nu_\tau} = \tilde{h}_3\langle\phi\rangle \\ m_\mu = h_2\langle\phi\rangle + k_2\langle\eta\rangle, \quad m_{\nu_\mu} = \tilde{h}_2\langle\phi\rangle + \tilde{k}_2\langle\eta\rangle, \quad (5) \\ m_{\mu'} = h_2\langle\phi\rangle - k_2\langle\eta\rangle, \quad m_{\nu_{\mu'}} = \tilde{h}_2\langle\phi\rangle - \tilde{k}_2\langle\eta\rangle,$$

The required lepton masses can be generated by choosing the appropriate values of Yukawas.

3 Dark Matter Phenomenology

In this model, the 4th generation right-handed neutral lepton ($\nu_{\mu_R}' \equiv \chi$) is identified as dark matter. The only possible dark matter annihilation final states are $(\mu^+ \mu^-)$ and $(\nu_\mu^c \nu_\mu)$. To get the correct relic density [8], we use the Breit-Wigner resonant enhancement and take $M_{\theta_3} \simeq 2m_\chi$. By taking the 4th generation charged lepton μ' heavier than χ , the dark matter stability is insured. The annihilation rate of χ for a single channel in the limit of massless leptons, is given as

Table 1 The Representation of the various fields in the model under the gauge group $G_{STD} \times SU(2)_{HV}$. Here i and α are the $SU(2)_L$ and $SU(2)_{HV}$ indices respectively, which run through the value 1 and 2.

Particles	$G_{STD} \times SU(2)_{HV}$ quantum numbers
$\psi_{eLi} \equiv (\nu_e, e)$	$(1, 2, -1, 1)$
$\Psi_{Li\alpha} \equiv (\psi_\mu, \psi_{\mu'})$	$(1, 2, -1, 2)$
$\psi_{\tau Li} \equiv (\nu_\tau, \tau)$	$(1, 2, -1, 1)$
$E_{R\alpha} \equiv (\mu_R, \mu'_R)$	$(1, 1, -2, 2)$
$N_{R\alpha} \equiv (\nu_{\mu R}, \nu_{\mu' R})$	$(1, 1, 0, 2)$
e_R, τ_R	$(1, 1, -2, 1)$
$\nu_{eR}, \nu_{\tau R}$	$(1, 1, 0, 1)$
ϕ_i	$(1, 2, 1, 1)$
$\eta_{i\alpha}^\beta$	$(1, 2, 1, 3)$
χ_α	$(1, 1, 0, 2)$

$$\sigma v = \frac{1}{16\pi} \frac{g_H^4 m_\chi^2}{(s - M_{\theta_3}^2)^2 + \Gamma_{\theta_3}^2 M_{\theta_3}^2} \quad (6)$$

where g_H is the horizontal gauge boson coupling, m_χ the dark matter mass, M_{θ_3} and Γ_{θ_3} are the mass and the decay width of $SU(2)_{HV}$ gauge boson respectively. By calculating thermal average of annihilation cross-section rate using eq.(6) and solving Boltzmann equation, we get the desired relic density of dark matter. The required parameters for getting the correct relic density is given in table.2.

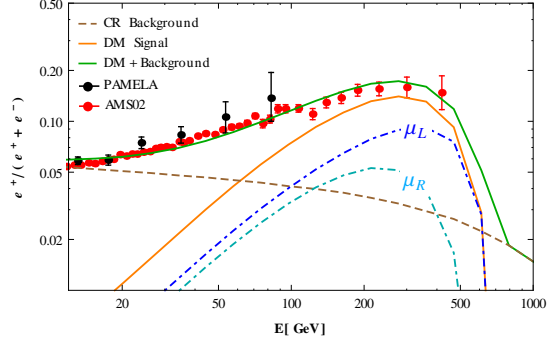
In this model, the dark matter annihilates to $\mu^+ \mu^-$ final state and their

Table 2 Numerical values of the parameters.

g_H	y_h	y_A	y_{H^\pm}	m_χ	$m_{\mu'}$	M_{θ_3, θ^+}	m_{H^\pm}
0.087	0.037	0.020	0.1	700 GeV	740 GeV	1400 GeV	1700 GeV

further decay produce positrons, which we use to explain the positron excess seen at AMS-02. We use the publicly available code PPPC4DMID to compute the positron spectrum $\frac{dN_{e^+}}{dE}$ and then forward it to the GALPROP code for its propagation. To fit the AMS-02 data, the required cross-section (CS) in the GALPROP is $\sigma v_{\chi\chi \rightarrow \mu^+ \mu^-} = 2.3 \times 10^{-25} \text{cm}^3 \text{s}^{-1}$. The annihilation CS for μ final state from eq.(6) is $\sigma v \approx 2.8 \times 10^{-25} \text{cm}^3 \text{s}^{-1}$, which signify that in the fitting of AMS-02 data, we do not need astrophysical boost factor. In fig.(1), we compare the output of GALPROP code to the AMS-02 data and find it in well agreement with the data.

Fig. 1 The positron flux spectrum measured by AMS-02 [2] and PAMELA [3] (red and black points respectively) and best fit using the contributions of different channels (μ_L , μ_R) in our model.



4 Muon magnetic moment

The $SU(2)_{HV}$ symmetry gives additional contributions to the muon $g-2$. The diagrams containing gauge boson θ^+ and scalar $\eta_{i\alpha}^\beta$ cause extra contributions to muon $g-2$. In the limit of $M_{\theta^+}^2 \gg m_{\mu'}^2$, the contribution from $SU(2)_{HV}$ gauge boson θ^+ comes,

$$[\Delta a_\mu]_{\theta^+} = \frac{g_H^2}{8\pi^2} \left(\frac{m_\mu m_{\mu'} - 2/3 m_\mu^2}{M_{\theta^+}^2} \right) \quad (7)$$

we note from the first term in eq.(7) that there is $m_\mu m_{\mu'}$ enhancement in the muon ($g-2$). In the limits $m_{\mu'}^2 \gg m_h^2$, $m_{\mu'}^2 \gg m_A^2$, the contribution to muon $g-2$ from neutral higgs η (CP-even h and CP-odd A) comes,

$$[\Delta a_\mu]_{h,A} = \frac{1}{8\pi^2} \left(\frac{3m_\mu m_{\mu'} (y_h^2 - y_A^2) + m_\mu^2 (y_h^2 + y_A^2)}{6m_{\mu'}^2} \right) \quad (8)$$

where y_h and y_A are the Yukawa couplings of CP-even and CP-odd higgs respectively. In the similar way, the contribution from the charged higgs η^\pm is given by,

$$[\Delta a_\mu]_{H^\pm} = -\frac{y_{H^\pm}^2}{8\pi^2} \left(\frac{3m_\mu m_{\nu_{\mu'}} + m_\mu^2}{6m_{H^\pm}^2} \right) \quad (9)$$

The total contribution to the muon anomalous magnetic moment is given as,

$$\Delta a_\mu = [\Delta a_\mu]_{\theta^+} + [\Delta a_\mu]_{h,A} + [\Delta a_\mu]_{H^\pm} \quad (10)$$

by taking into account the parameters shown in table.2, we finally get,

$$\Delta a_\mu = 2.9 \times 10^{-9} \quad (11)$$

which is in agreement with the experimental result [1] within 1σ .

5 Conclusion

We studied a 4th generation extension of SM introducing $SU(2)_{HV}$ gauge symmetry between 4th generation fermions and muon families. We identified the 4th generation neutral lepton as dark matter and proposed a common explanation for AMS-02 positron excess and muon anomalous magnetic moment. The dark matter annihilates through $SU(2)_{HV}$ gauge boson θ_3 and gives the correct relic density. The muons produced from the dark matter annihilation further decays and give positrons, which is used for the explanation of AMS-02 positron excess. The $SU(2)_{HV}$ gauge boson θ^+ and scalars give the additional contributions to the muon $g - 2$. We found that for suitable choice of parameters, it is possible to get muon $g - 2$ within 1σ of the BNL measurement.

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References

1. G. W. Bennett *et al.* [Muon ($g-2$) Collaboration], Phys. Rev. D **80**, 052008 (2009) [arXiv:0811.1207 [hep-ex]].
2. L. Accardo *et al.* [AMS Collaboration], Phys. Rev. Lett. **113**, 121101 (2014).
3. O. Adriani *et al.* [PAMELA Collaboration], Nature **458**, 607 (2009) [arXiv:0810.4995 [astro-ph]].
4. J. Beringer *et al.* [Particle Data Group Collaboration], Phys. Rev. D **86**, 010001 (2012).
5. T. Moroi, Phys. Rev. D **53**, 6565 (1996) [Erratum-ibid. D **56**, 4424 (1997)] [hep-ph/9512396].
6. S. Baek, N. G. Deshpande, X. G. He and P. Ko, Phys. Rev. D **64**, 055006 (2001) [hep-ph/0104141].
7. G. Tomar and S. Mohanty, JHEP **1411**, 133 (2014) [arXiv:1403.6301 [hep-ph]].
8. P. A. R. Ade *et al.* [Planck Collaboration], arXiv:1303.5076 [astro-ph.CO].